Correlations between different sources of contrast at 9.4T: diffusion *vs.* susceptibility

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Target audience: diffusion tensor imaging contrast, magnetic susceptibility contrast, phase contrast, high magnetic field, rat brain.

Introduction:

Diffusion Tensor Imaging (DTI) and Quantitative Susceptibility Mapping (QSM) are two MR techniques used to probe brain microstructure. Through a complete description of water diffusion in the tissue, DTI gives useful information about the white matter (WM) such as fiber direction[1] or integrity[2]. The phase of gradient echo MR images is sensitive to differences in the resonance frequency and, as such, has been used to create anatomical images with excellent contrast between white and grey matter especially at ultra-high magnetic field[3]. Same kind of contrast can be obtained on QSM where phase data are processed to extract the underlying magnetic susceptibility distribution, resulting in a novel quantitative anatomical contrast of an intrinsic physical tissue property[4]. Fiber direction, iron and/or myelin are known to influence the susceptibility contrast but, the exact origin of this contrast is not fully understood. Even if the contrast mechanisms of these two techniques are different (*i.e.* spin mobility for diffusion *vs.* spatial susceptibility distribution for susceptibility), several similarities such as an influence of myelin and fiber orientation are known[3,4]. The aim of this work was to investigate the potential cross correlations between DTI and QSM in the rat brain white matter at ultra-high magnetic field.

Materials and methods:

All MR experiments were performed on an actively-shielded 9.4T/31cm magnet (Varian/Magnex) equipped with 12-cm gradient coils (400mT/m, 120µs) with a quadrature transceive 20-mm surface RF coil. For each rat (n=6), DTI acquisition was performed using a semi-adiabatic double spin-echo sequence[5] with the following parameters: Icosahedral 21 directions diffusion gradient sampling scheme (b = 1000 s.mm^{-2}), FOV = 23 × 15 mm^2, matrix size = 128 × 64 zero-filled to 512 × 340, 9 slices of 0.8 mm thickness in the axial plane, 8 averages with TE/TR = 42/2000 ms. Gradient-echo MR images at two different echo times (TE = 6.5 and 18 ms, TR = 900 ms, FOV = 23×15 mm^2, Matrix size = 512 × 340, 22 slices of 0.4 mm thickness and 8 repetitions) were acquired for QSM.

Data analyses were performed with homemade Matlab software. Diffusion tensor derived parameters: diffusivities (ADC, $D_{//}$ and $D_{\perp}$) and fractional anisotropy (FA) values were derived from the tensor. Large scale phase shifts due to magnetic susceptibility differences between air and tissue and imperfect shimming were removed using the SHARP algorithm[3]. Susceptibility maps were then calculated using regularized single-orientation (RSO) method[4]. Regions of interest (ROIs) were manually delimited in different white matter structures: corpus callosum (CC), external capsule (EC), Cingulum (Cg) and hippocampus (Hp). Diffusion tensor derived parameters as well as susceptibilities were averaged in these ROIs and correlations between these parameters were assessed by using Matlab functions.

Results:

Maps derived from DTI (FA and DEC maps) and QSM (Phase and χ maps) exhibited a superb contrast between WM and GM (Fig. 1A) especially for the principal bundles of fibers such as CC (Fig. 1B). In myelinated regions with very low FA such as hippocampal layers (C) the contrast is very low on χ maps whereas one can clearly distinguish the different layers on DEC maps. In cingulum (B) and external capsule (D), χ was inversely correlated to FA (R = -0.36, P = 0.01 and R = -0.44, P = 0.0016 for Cg and EC, respectively) and positively correlated to $D_{\perp}$ (R = 0.35, P = 0.01 and R = 0.55, P = 0.0001 for Cg and EC, respectively). Indeed, the variation of χ through over the different slices in these structures follows the same trend as $D_{\perp}$ but an opposite to $D_{//}$ and FA (data not shown).

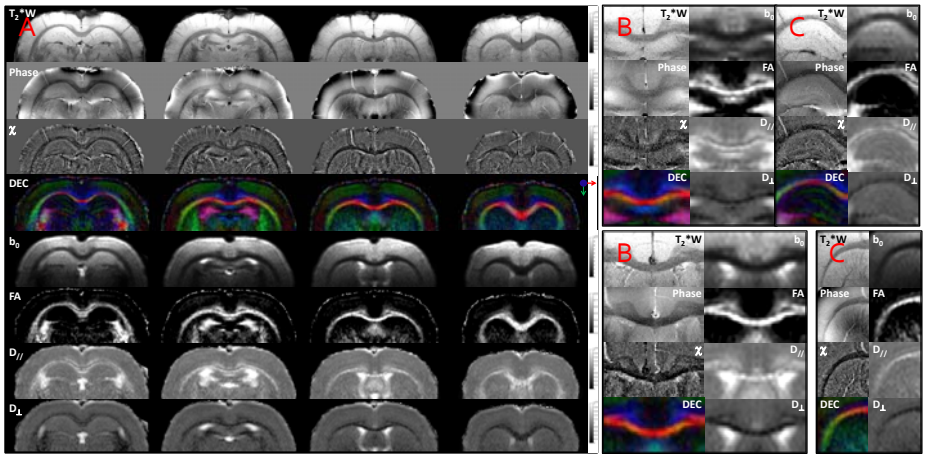

Figure 1: *A: T_2*W images, phase maps, susceptibility maps (χ), direction encoded color maps (DEC), b_0 image, FA map, $D_{//}$ and $D_{\perp}$ maps for a typical rat brain. B: zoom in the CC and Cg on two different slices. C: zoom in the external capsule on two different slices.*

Discussion and conclusion:

This study confirms that DTI and QSM are two major tools to probe brain microstructure, exhibiting an excellent contrast between WM and GM for both modalities[3-5]. The WM/GM contrast obtained on χ maps was much more pronounced on external capsule (right-left then up-down orientation) and corpus callosum (right-left orientation) than cingulum (front-rear orientation), meaning that the contrast on χ maps is better in fibers orthogonal than in fibers parallel to the main magnetic field B_0 (front-rear orientation). Absence of contrast on χ maps in myelinated regions with low FA suggests an effect of not only the myelin but also the fiber organization to the phase and χ contrasts. According to the variations of χ through over the different slices in the various WM structures assessed and the correlations observed between χ and the DTI derived parameters, one can imagine an effect of the axonal compaction/axonal diameter on the χ contrast.

References: 1. Basser PJ. et al. MRM 2000. 2. van de Looij Y. et al. NMR in Biomed 2011. 3. Schweser F et al., Neuroimage 2011. 4. De Rochefort L. et al. MRM 2010. 5. van de Looij Y. et al. MRM 2011.

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